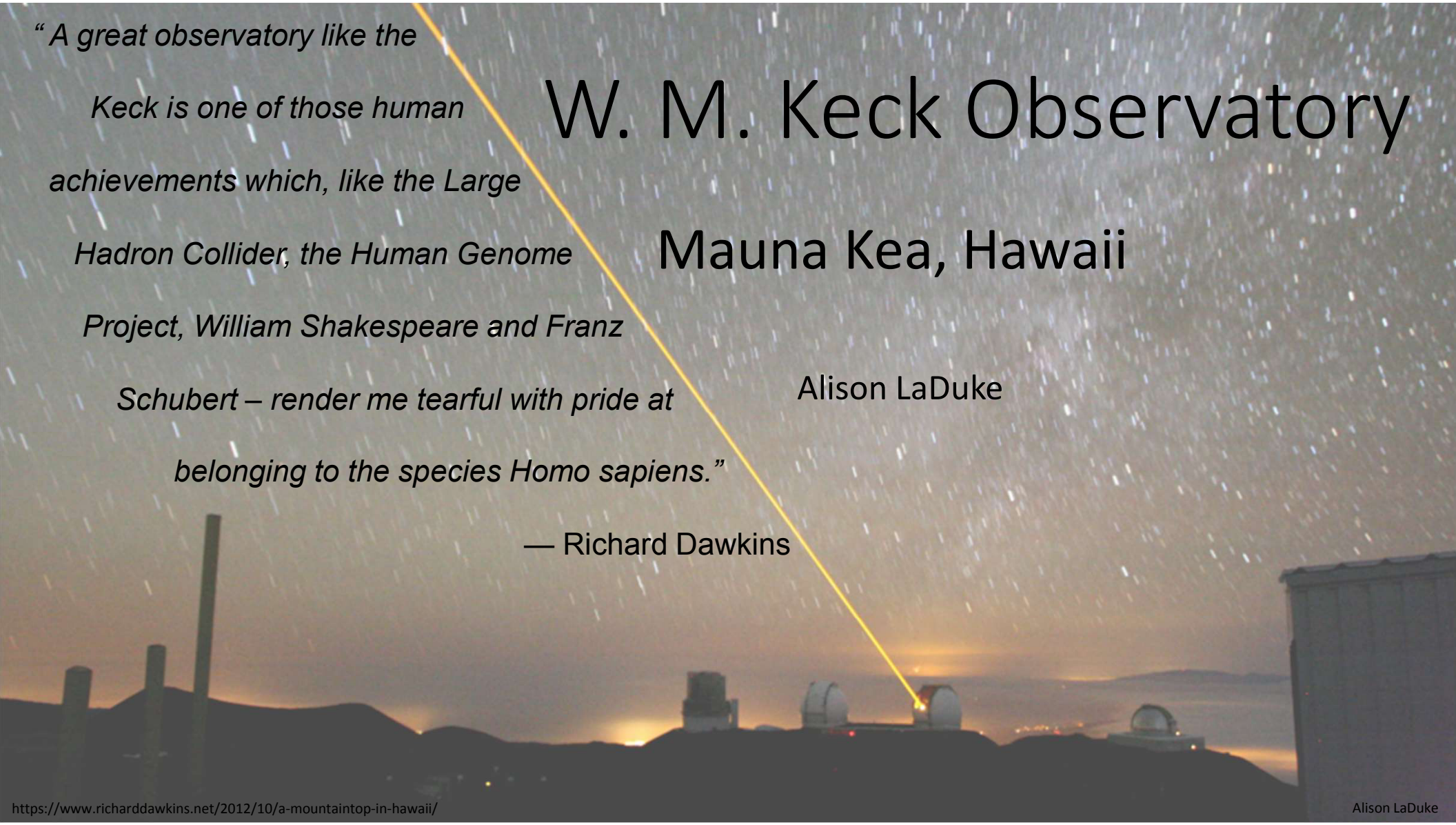


W. M. Keck Observatory

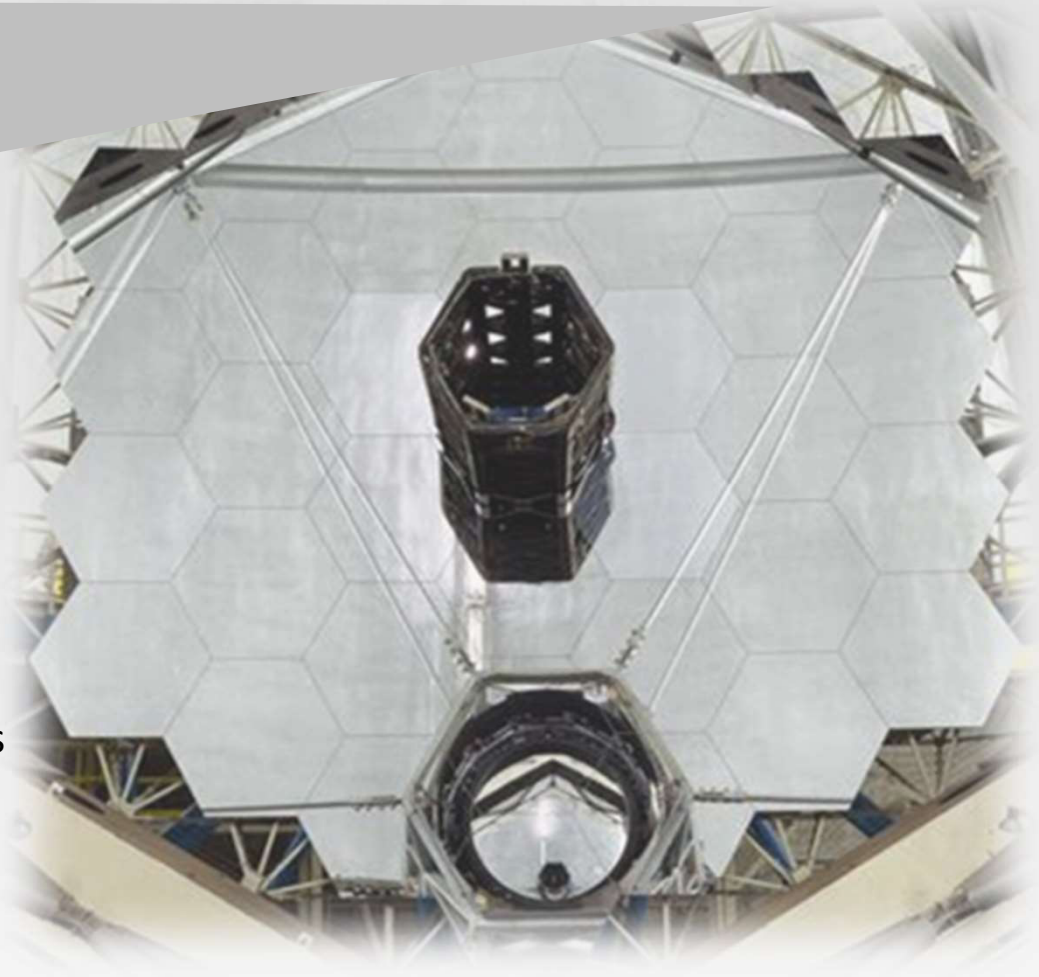
Mauna Kea, Hawaii

Alison LaDuke

https://www.richarddawkins.net/2012/10/a-mountaintop-in-hawaii/

Alison LaDuke

Design and Instrumentation



- Two optical-infrared telescopes
  - 10-meter primary mirrors
  - 36 hexagonal mirror segments
  - Altazimuth mount
  - Interferometry
  - Active optics correct for mechanical stresses
  - Adaptive optics correct for atmospheric distortions
- Spectrometry and Imaging
  - HIRES echelle spectrometer: exoplanet detection
  - KCWI integral field spectrograph: spatially-resolve extended objects from their spectra
  - LRIS imaging spectrograph: images faint galaxies and galactic clusters

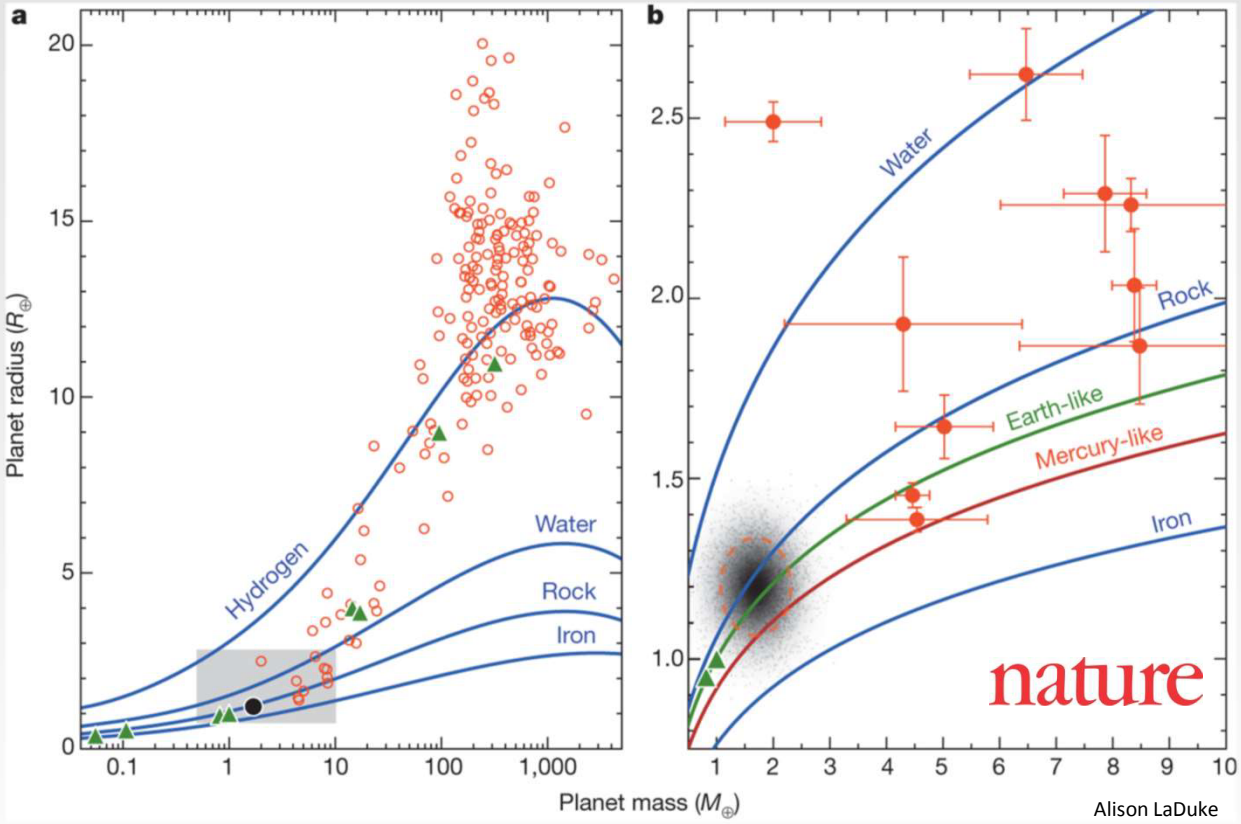
http://www.keckobservatory.org/

A rocky composition
for an Earth-sized exoplanet

- Published during the discovery of Kepler-78b
- Keck I Telescope took data over 45 days
- Measured radial velocities using HIRES

- Constrained mass to be $1.69 \pm 0.41\ M_{\oplus}$
- Constrained radius to be $1.2 \pm 0.09\ R_{\oplus}$
- Estimated density to be $5.3 \pm 1.8\ g\ cm^{-3}$

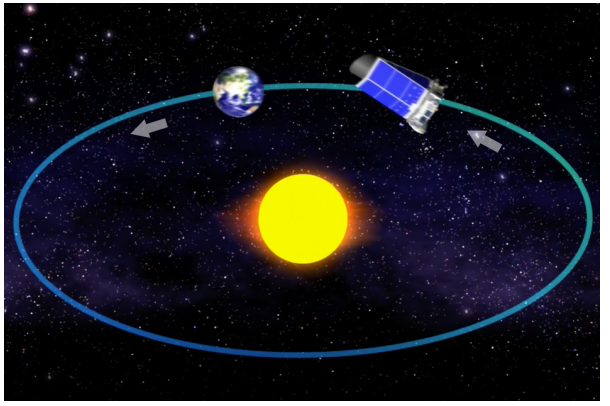
- Kepler-78b is likely made of rock and iron

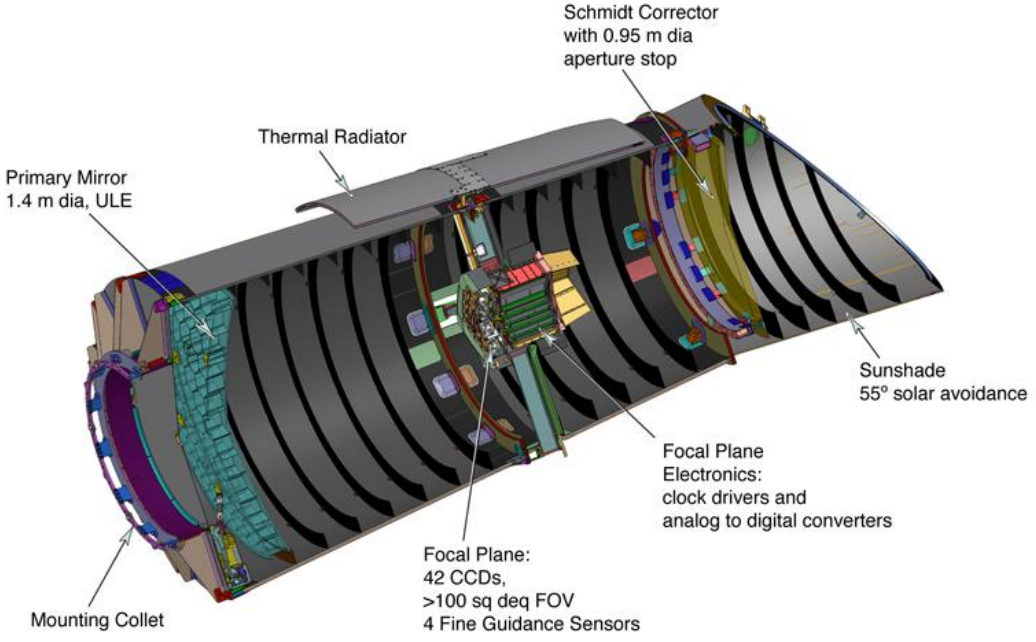


AW Howard *et al. Nature* **000**, 1-4 (2013) doi:10.1038/nature12767

Alison LaDuke

Kepler Space Telescope:
Instrumentation and Design



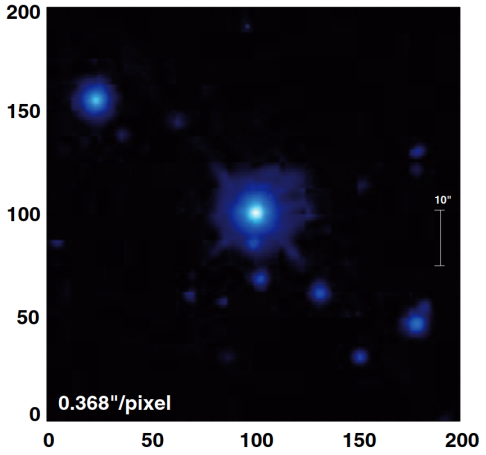


Kepler-22b: A 2.4 EARTH-RADIUS PLANET IN THE HABITABLE ZONE OF A SUN-LIKE STAR

William J. Borucki[1], David G. Koch[1], Natalie Batalha[2], Stephen T. Bryson[1], Jason Rowe[3], Francois Fressin[4], Guillermo Torres[4], Douglas A. Caldwell[3], Jørgen Christensen-Dalsgaard[5,6], William D. Cochran[7] +Show full author list

Published 2012 January 6 •

The Astrophysical Journal, Volume 745, Number 2



- Kepler-22b is the first known transiting planet to orbit within the habitable zone of a Sun-like star.
- Orbital period of 290 days.
- Series of tests to avoid false positives.
- Final validation from radial velocity measurements from Keck 1.
- The radiative equilibrium temperature is 262 K.
- Upper limit on mass: 36 Earth masses at 1-sigma confidence.

Gemini Telescope Pair

Gemini South:

- 8.1m diameter telescope at 8,900 ft of elevation
- Cerro Pachón, Chilean Andes
- GSAOI system adaptive optics with 87 arc-second square field
- Uses natural or five laser guide stars

Gemini North:

- 8.1m diameter telescope at 13,800 ft of elevation
- Mauna Kea, Hawaii
- ALTAIR system adaptive optics with 22.5 arc-second square field
- Uses natural or single laser guide star

Both:

- Primary mirror with silver coatings
- Optimized for IR observations
- Spectrographs (GMOS) optimized for far red light (700-1000nm)
- Near IR imaging and spectroscopy
- GPI: adaptive optics polarimeter/spectrometer (direct imaging of planets)

Use of Gemini Data

Data published on Jun 29th, 2010.

First direct imaging of a planet around a sun-like star from initial detection in April 2008.

Team confirmed proper motion, and determined temperature and mass.

330 AU from host star, 1800K, 0.008 solar masses.

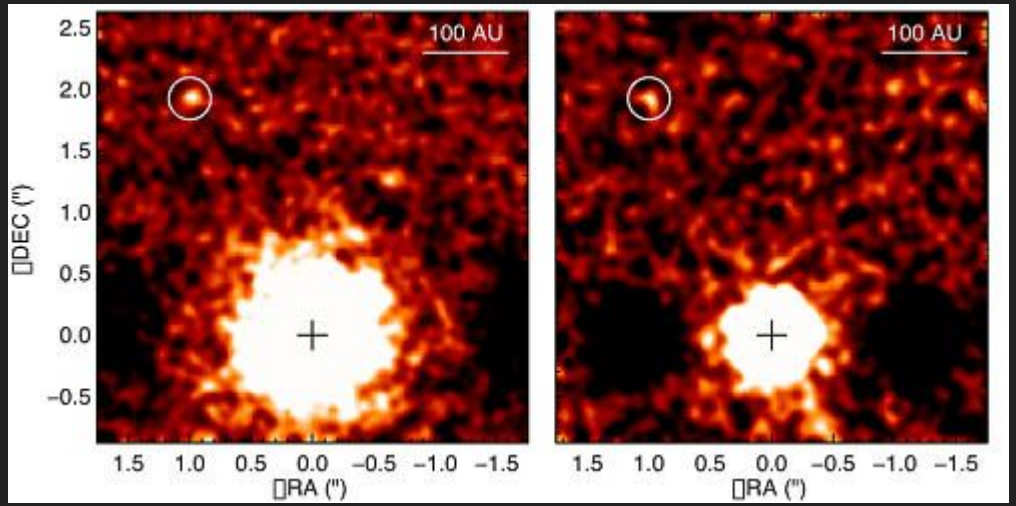


Figure: images of 1RXS J160929 at 3.05 (left) and 3.8 (right) microns. Images obtained via Near Infrared Imager (NIRI) with adaptive optics ALTAIR.

arXiv: 1006.3070

Sources

"Gemini Facilities." *National Optical Astronomy Observatory*, National Science Foundation, http://ast.noao.edu/facilities/gemini

"Revolutionary New Instrument Propels Astronomical Imaging to New Extremes." *Gemini Observatory*, http://www.gemini.edu/node/11715.

"Gemini Observatory." *Gemini Observatory,* http://www.gemini.edu/gallery

Gemini Observatory-Gallery." *Gemini Observatory,* www.gemini.edu/node

"First Directly Imaged Planet Confirmed Around Sun-Like Star." *Gemini Observatory*, https://www.gemini.edu/node/11486

"Instruments-GMOS." *Gemini Observatory,* https://www.gemini.edu/sciops/instruments/gmos/

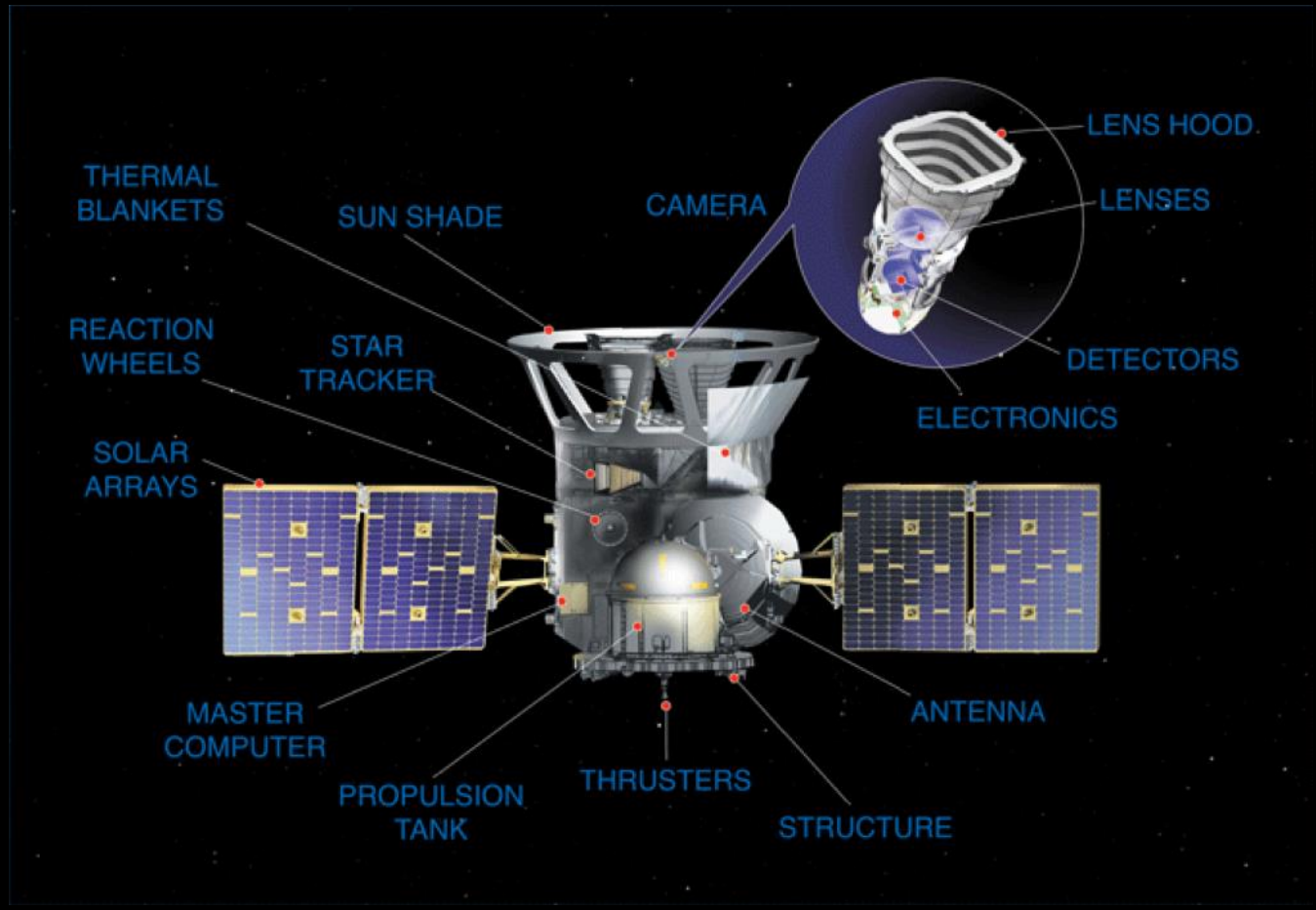
"Gemini Meetings." *National Optical Astronomy Observatory,* National Science Foundation, https://www.noao.edu/meetings/ao-aas/talks/Christou_Gemini_AO_AAS.pdf

Lafrenière, David, et al. "The Directly Imaged Planet Around The Young Solar Analog 1Rxs J160929.1 – 210524: Confirmation Of Common Proper Motion, Temperature, And Mass." *The Astrophysical Journal*, vol. 719, no. 1, 2010, pp. 497–504., doi:10.1088/0004-637x/719/1/497.

McDonald, Rebecca. "Planet Imager." *Planet Imager*, Exoplanet Survey, planetimager.org/.

Transiting Exoplanet Survey Satellite (TESS)

- TESS is a space satellite orbiting earth.
- Four identical cameras are used for imaging, each with a 24x24 degree field of view.
- Each camera has an optical bandpass covering ~600nm-1000nm. The resolution per pixel is 21”.
- On April 18, 2018 the satellite launched into a highly elliptical orbit. It is intended to have a two-year survey.

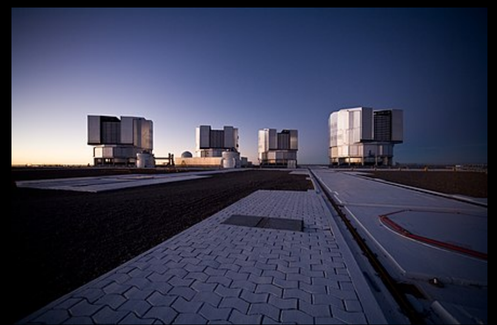


TESS Mission

- TESS' mission is to identify exoplanets by the transit method. It will also target about 20,000 requested objects during its mission.
- It produces full frame images that can then be broken down for targeting a small subset of pixels.
- Recently, an earth sized exoplanet (TOI 700d) was discovered in the habitable zone of a red dwarf 101.4 ly away.

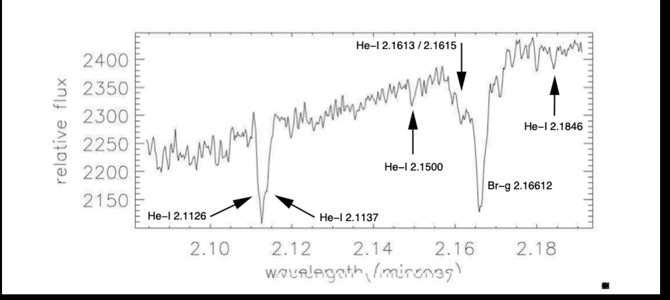
Very Large Telescope (VLT)

- Four large 8.2 meter Unit Telescopes (UT) and four smaller 1.8 meter Auxiliary Telescopes (AT)
- UT names (Mapuche origin): Antu, Kueyen, Melipal, Yepun
- Three main modes:
  - As four independent telescopes using the UTs (primary use)
  - As a single large interferometer (VLT Interferometer or VLTI). ATs are dedicated to interferometry and allow the VLTI to operate every night
  - As a single large incoherent instrument (different frequencies of light and out of phase) for optimal light gathering

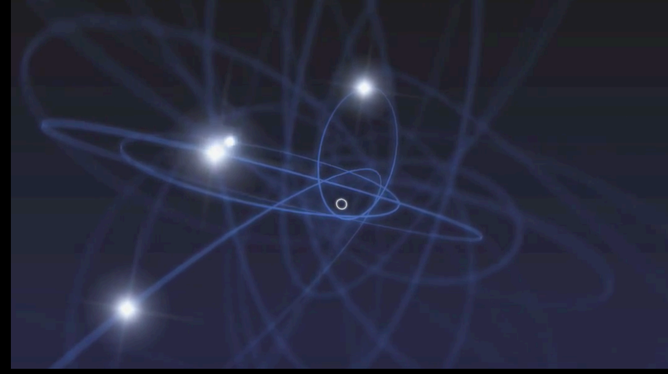


- Largest number of instruments for any single observatory
- Examples:
  - ESPRESSO (Echelle Spectrograph for Rocky Exoplanet and Stable Spectroscopic Observations) - Used for searching for habitable zone exoplanets using spectroscopy and radial velocity precision
  - FLAMES (Fibre Large Array Multi-Element Spectrograph) - Allows for studying hundreds of individual stars at once in nearby galaxies
- Spectrometers: ESPRESSO, FLAMES, FORS2, KMOS, MUSE, NACO, SINFONI, UVES, VIMOS, VISIR, X-SHOOTER
- Imagers: FORS2, GRAVITY, HAWK-I, NACO, PIONEER
- Adaptive Optics: NACO, SPHERE

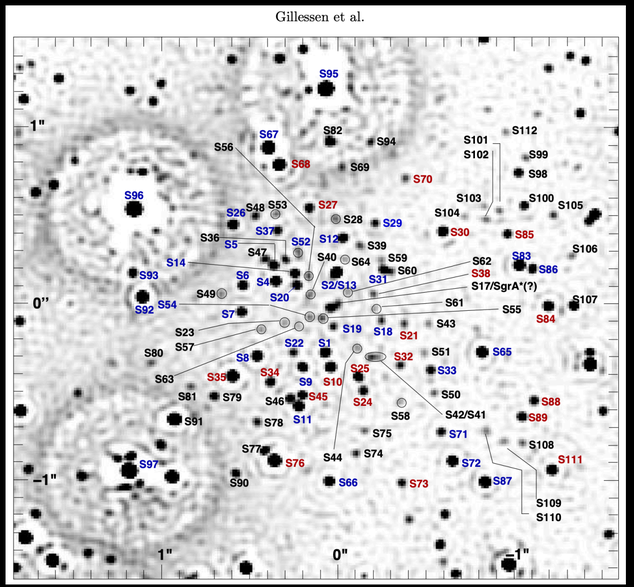
Source: Very Large Telescope — Wikipedia



VLT Results



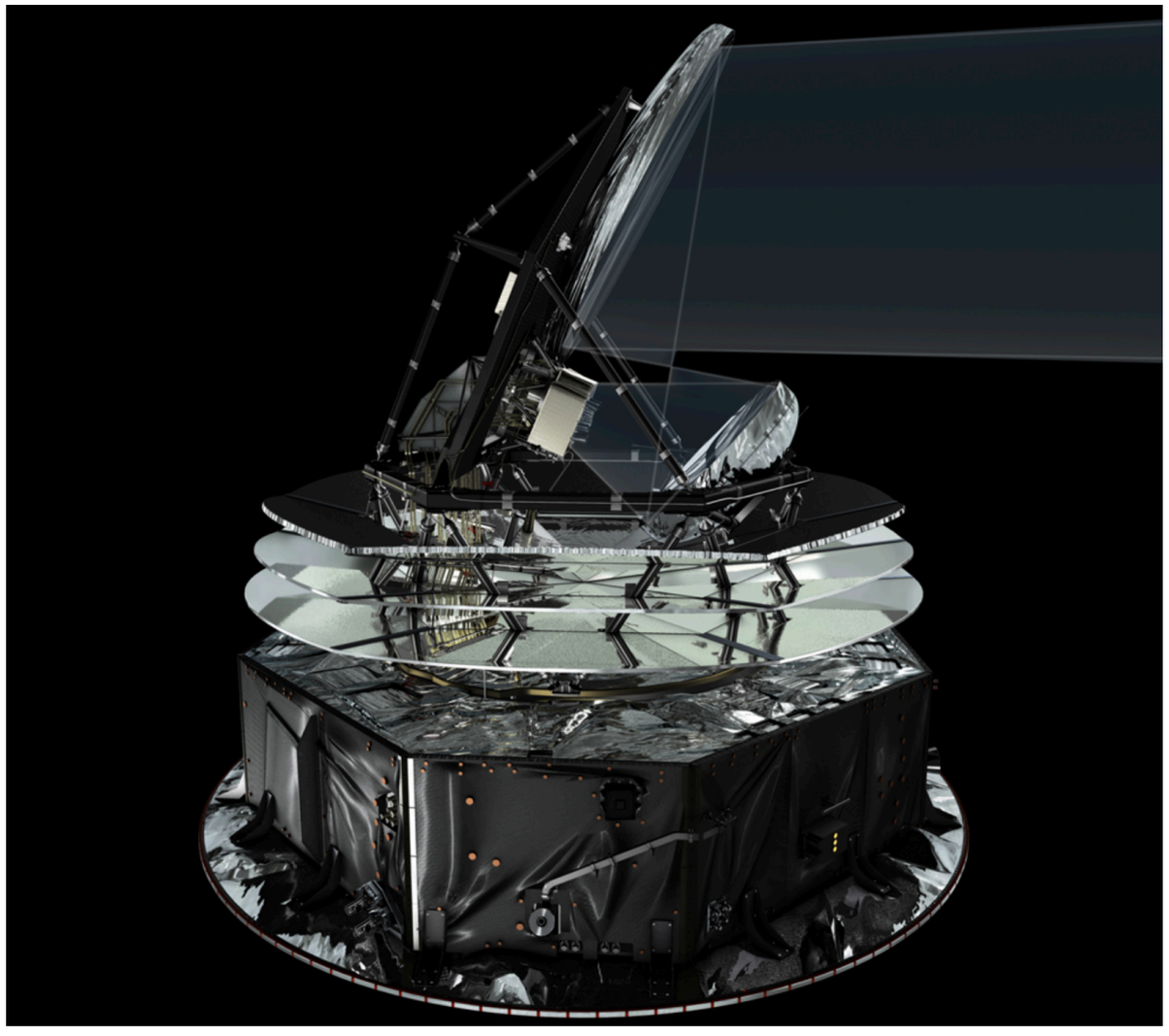
- Gillesen et. al. — Monitoring stellar orbits around the Massive Black Hole in the Galactic Center
- 16 year study of stars near Srg A* (black hole at the center of the Milky Way) using high resolution Near IR techniques
- Determined the orbits of 28 stars fit extremely well by a single point mass gravitational source
- Central object mass is $4.31 \pm 0.06(stat) \pm 0.36(R_0) \times 10^6 M\odot$
- https://www.youtube.com/watch?v=_2R3wwrI_f8 — (25 sec, motion of stars near Sgr A*)



- Other results:
  - Discovery of Beta Pictoris b, the first exoplanet discovered by direct imaging
  - Observing the afterglow of the furthest known gamma-ray burst
  - First successful test of GR on the motion of a star passing near a supermassive black hole
  - Estimated the age of first generation stars (13.4±0.8 billion years)

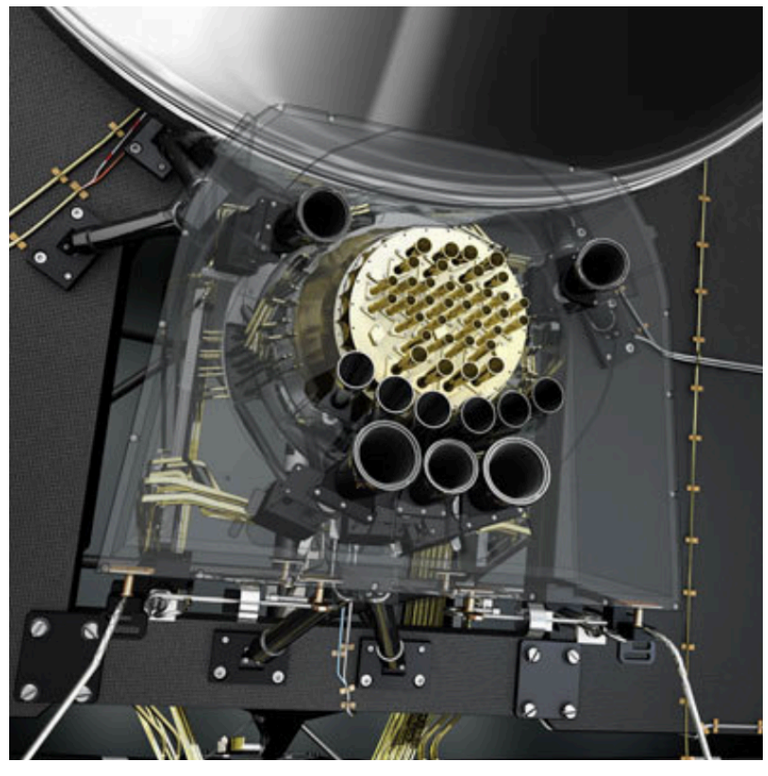
Sources: Very Large Telescope — Wikipedia
European Southern Observatory — eso0846
arXiv 0810.4674

Planck Space Telescope: Design and Instruments

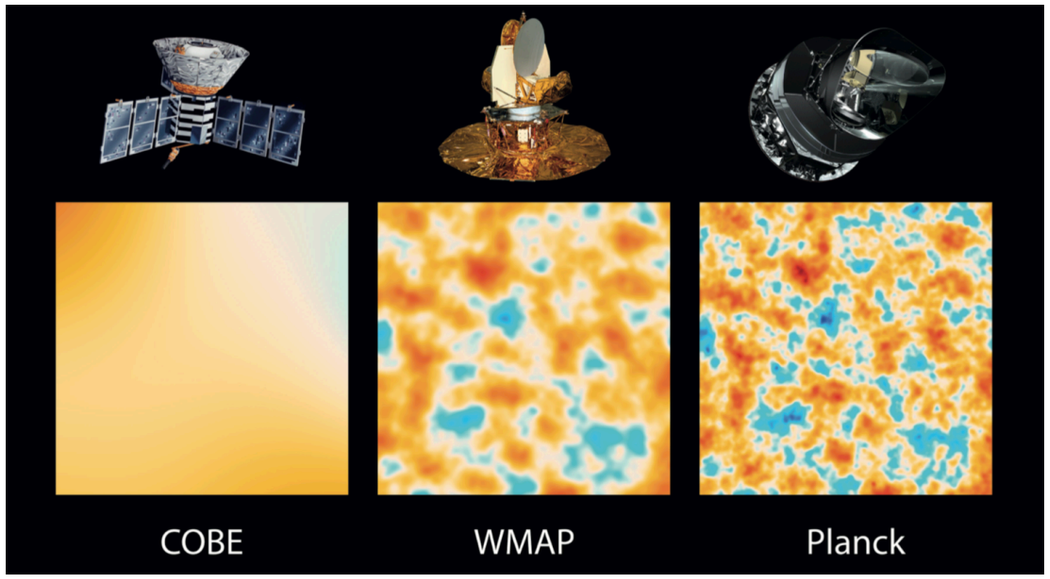


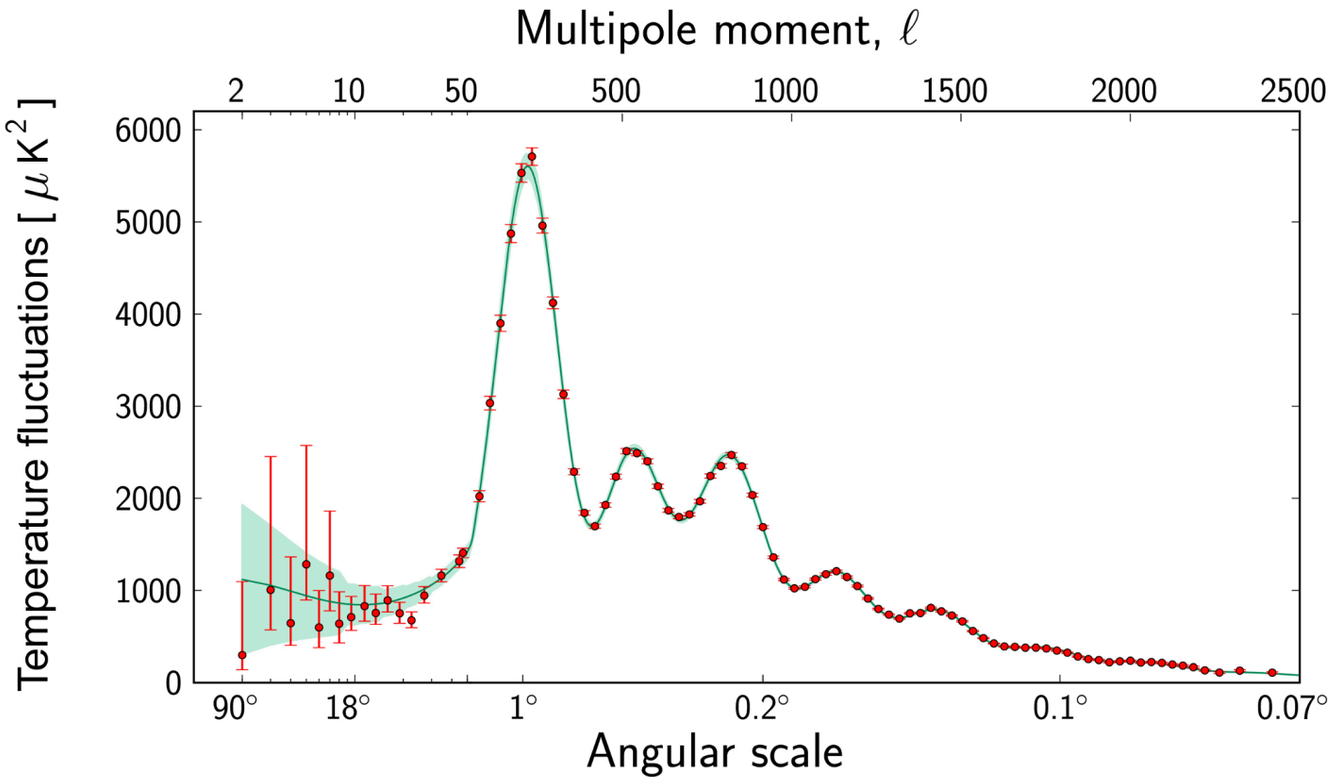
Planck (2009-2013) mapped CMB radiation
at microwave and infra-red frequencies.
Small angular resolution:
5 arcminutes->1.2m in diameter or larger
High sensitivity:
$\Delta T/T \sim 2.5\times10^{-6}$
Two instruments working with different technologies
and at different wavelength regimes are used.

The focal plane unit (FPU) is composed
of two sets of detectors: HFI and LFI.
HFI: 0.35mm to 3 mm
LFI: 4.3mm to 10 mm



Planck Space Telescope: Research Related





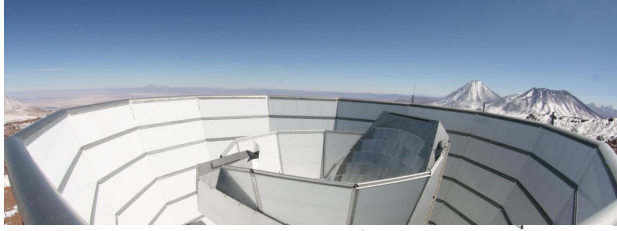
	Planck+WP	*Planck*+WP+BAO	*WMAP*-9
$\Omega_b h^2$	0.02206 ± 0.00028	0.02220 ± 0.00025	0.02309 ± 0.00130
$\Omega_c h^2$	0.1174 ± 0.0030	0.1161 ± 0.0028	0.1148 ± 0.0048
τ	0.095 ± 0.014	0.097 ± 0.014	0.089 ± 0.014
H_0	65.2 ± 1.8	66.7 ± 1.1	74 ± 11
n_s	0.974 ± 0.012	0.975 ± 0.012	0.973 ± 0.014
$\log(10^{10} A_s)$	3.106 ± 0.029	3.100 ± 0.029	3.090 ± 0.039
α/α_0	0.9936 ± 0.0043	0.9989 ± 0.0037	1.008 ± 0.020

Observations of CMB polarizations

Observation of CMB gravitational lensing

Creation of galaxy cluster catalog through Sunyaev-Zel’dovich effect

Atacama Cosmology Telescope (ACT)



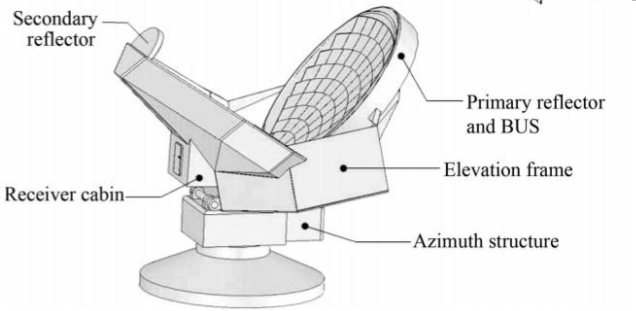
- Located on Cerro Toco in Northern Chile
  - Observations at 145, 215, and 280 GHz -- need high, dry conditions
- Bolometric detectors [MBAC, ACTPol, AdvACT]
  - 32 x 32 array of "transition edge sensor" bolometers at each frequency
  - 1.05 mm square detectors; each grid cooled to 0.3 K
  - Detector spacing: 1.05 mm (44") horizontal, 1.15 mm (48") vertical
- "Approximates an ideal aplanatic Gregorian telescope"
  - Primary: 6 m, 71 aluminum segments
  - Secondary: 2 m, 11 aluminum segments
  - Shapes of both described by:

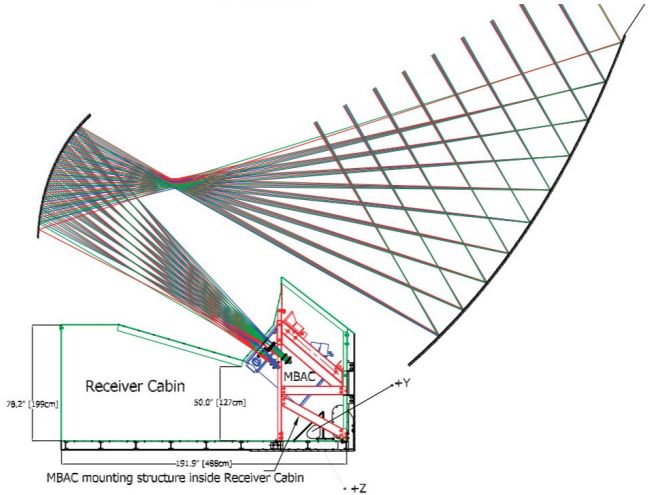
$$z(x,\ y) = z_{\text{vert}} + \frac{(x^2+y^2)/R}{1+\sqrt{1-(1+K)(x^2+y^2)/R^2}}$$

Table 2. Atacama Cosmology Telescope Mirror Shapes[a]

Mirror	z_{vert} (m)	R (m)	K	y_0 (m)	a (m)	b (m)
Primary	0.0000	−10.0000	−0.940935	5.000	3.000	3.000
Secondary	−6.6625	2.4938	−0.322366	−1.488	1.020	0.905
Gregorian focus[b]	−1.6758					

- Additional considerations:
  - Design eliminates leading-order spherical aberration and coma
  - Azimuthal rotation limits impact of drifting detector response
  - Some field distortion (horizontal stretching, shearing w.r.t. elevation)
  - Ghost images due to even # of reflections from the MBAC surfaces





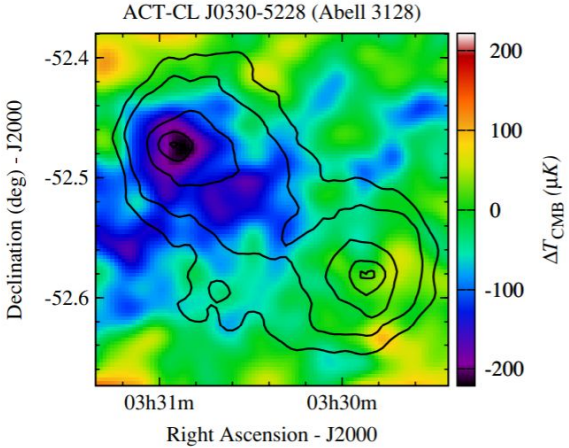
J.W. Fowler et. al. "Optical design of the Atacama Cosmology Telescope and the Millimeter Bolometric Array Camera" (2007). https://doi.org/10.1364/AO.46.003444

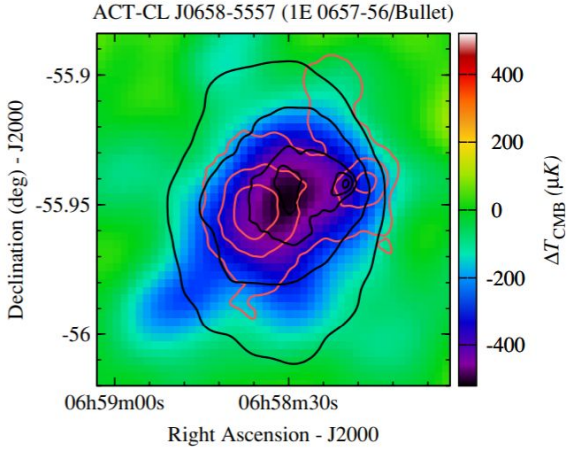
ACT Published Results

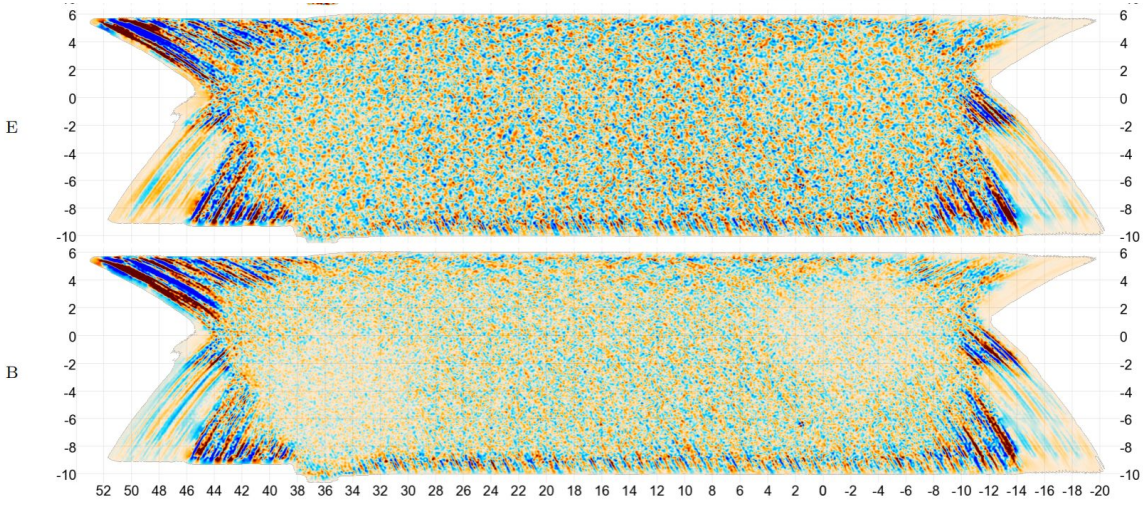
A.D. Hincks et. al. "THE ATACAMA COSMOLOGY TELESCOPE (ACT): BEAM PROFILES AND FIRST SZ CLUSTER MAPS". (2010).

Detecting galactic clusters through the Sunyaev–Zel'dovich (SZ) effect. Black outlines are X-ray emission (previous method for observing the clusters shown).

[Data taken with MBAC]





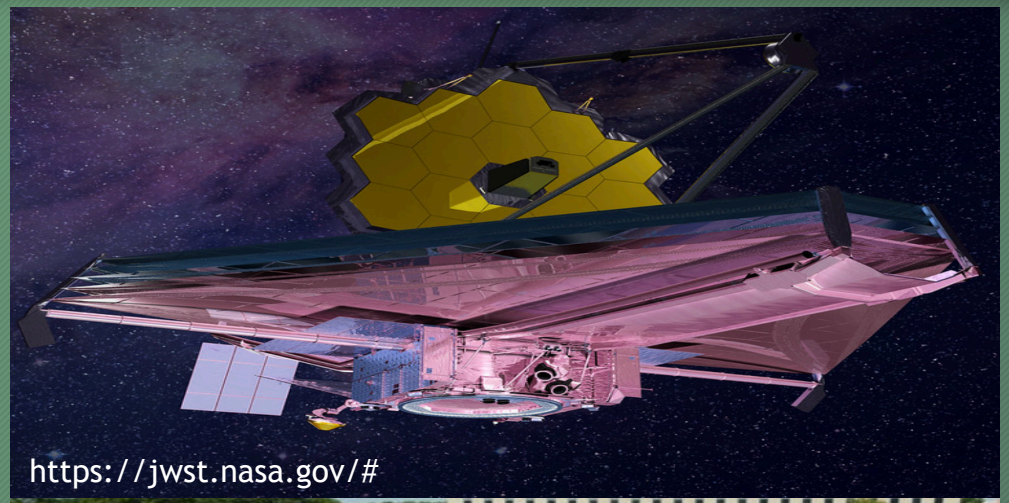


ACT observations of the CMB in equatorial coordinates, shown with 2 different filters.

[Data from MBAC and ACTPol]

T. Louis et al. "THE ATACAMA COSMOLOGY TELESCOPE: TWO-SEASON ACTPOL SPECTRA AND PARAMETERS." (2016).

James Webb Space Telescope



https://jwst.nasa.gov/#

https://jwst.nasa.gov/Webb3d/

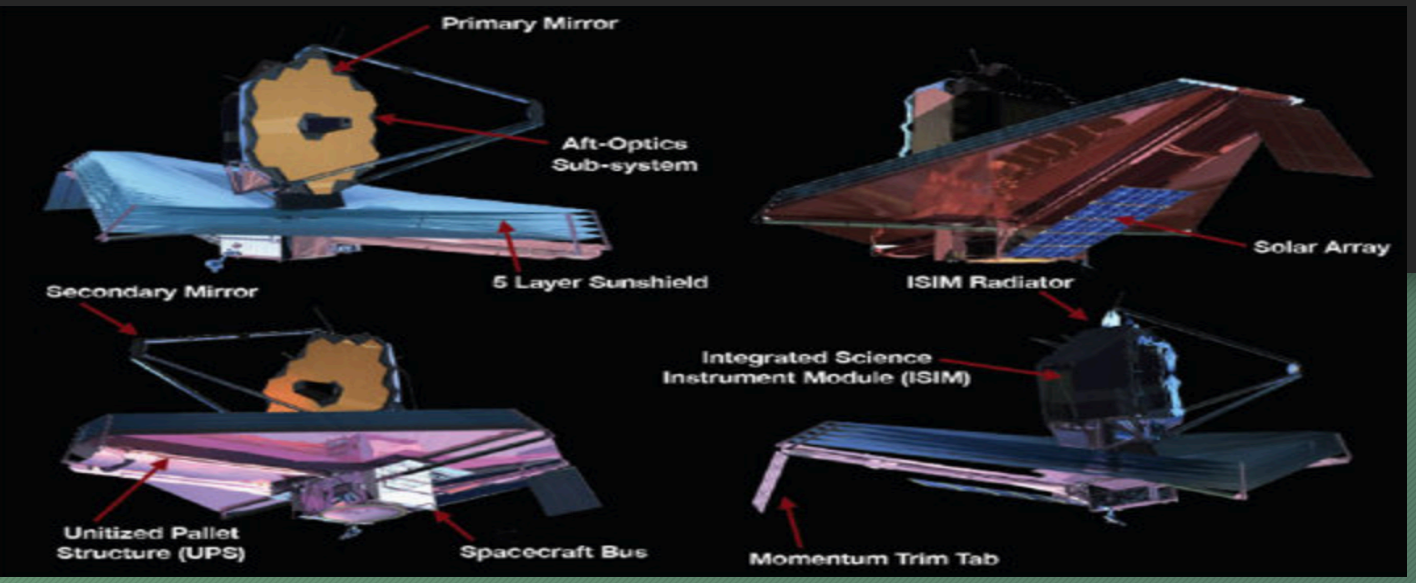
-Formerly known as the "*Next Generation Space Telescope*", the Webb was renamed after a former NASA administrator

-This telescope that will be shipped into space in ~2021. Will be largest telescope in place and much more powerful than Hubble

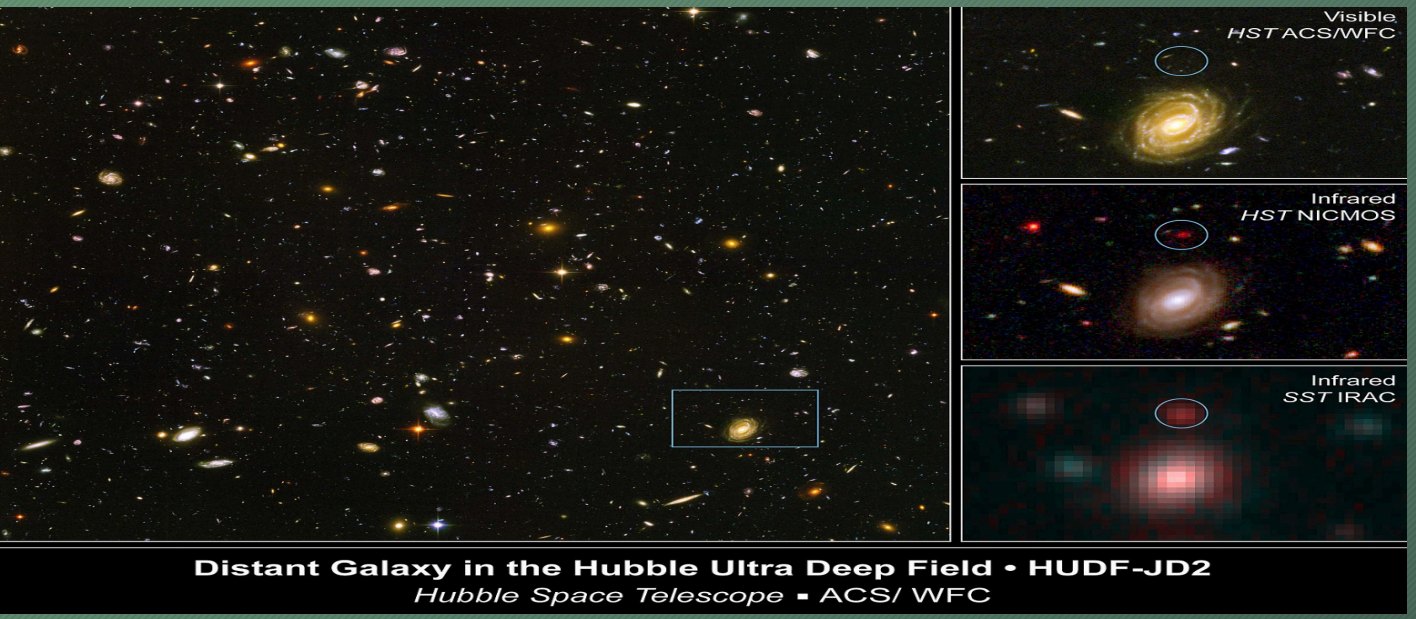
- Will use infrared vision to see 13.5 billion years into the past and into distant galaxies, but will still be used to observe our solar system

-Unlike Hubble (that orbits a few hundred kilometers from Earth) Webb will orbit the sun a million miles away from the Earth

-It will be able to operate at around -370F (50K) and with great sensitivity. "It could detect the heat signature of a bee at the from earth to the moon as well as see the details of a penny at 24 miles out"



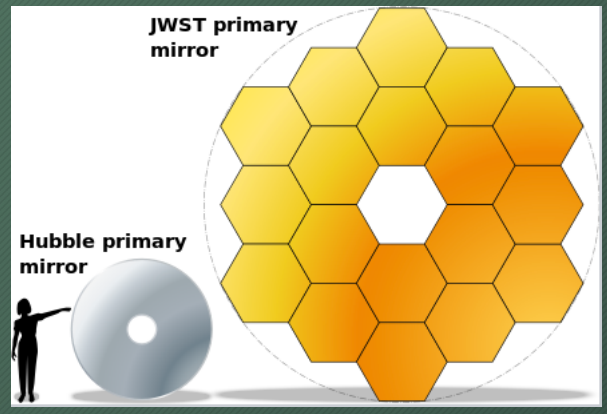
http://images.huffingtonpost.com/2014-01-02-JWST.jpg



https://upload.wikimedia.org/wikipedia/commons/0/0e/HUDF-JD2.jpg

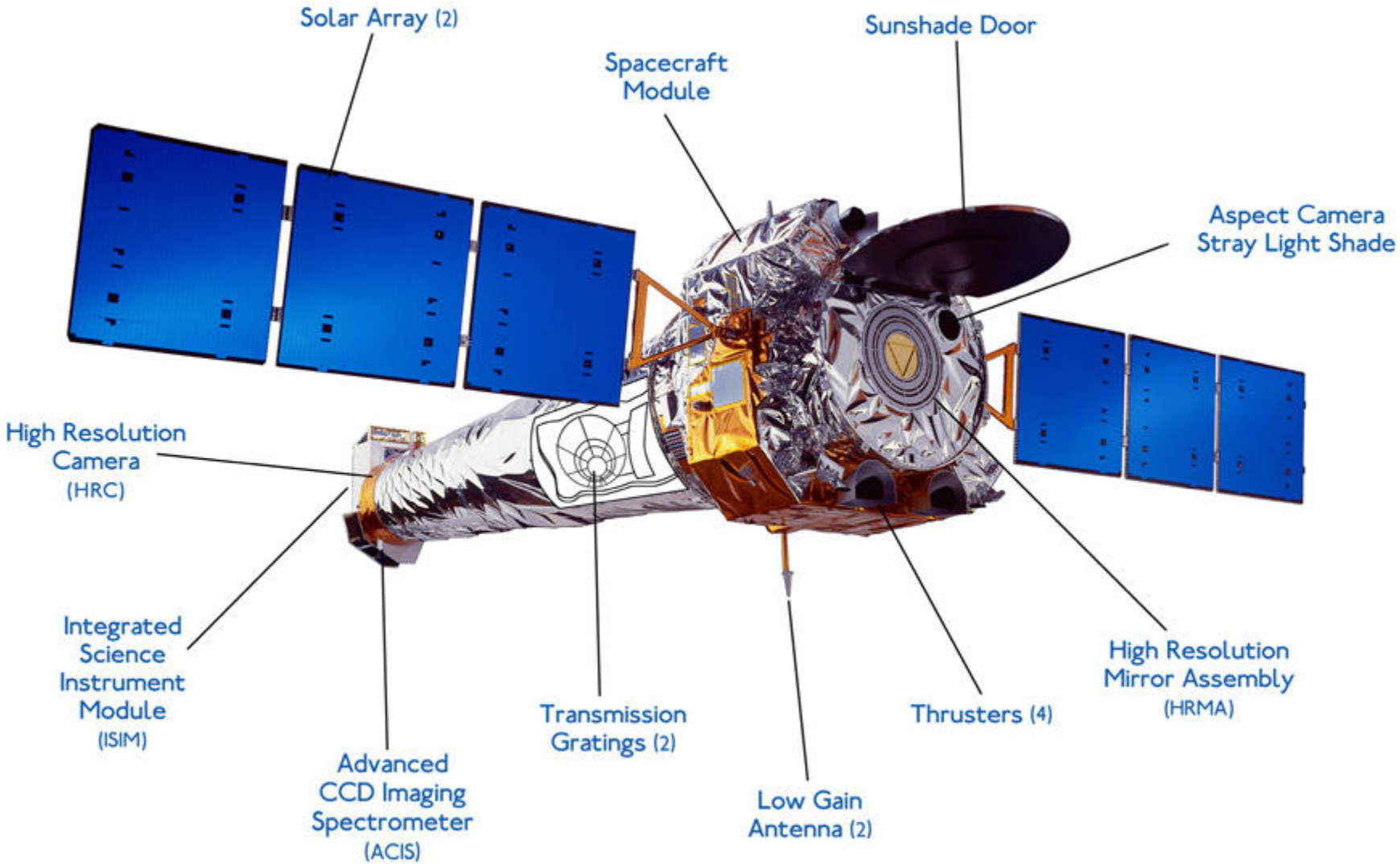
-Will be folded origami style to fit into the rocket when launched

-Has a five-layer sunshield



-The estimated cost is projected to be at $10 billion

NASA's Chandra X-Ray Observatory



Instrumentation and Discoveries

- High Resolution Camera (HRC)
- Advanced CCD Imaging Spectrometer (ACIS)
- High/Low Energy Transmission Grating Spectrometer (H/L ETGS)

Instrumentation and Discoveries

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M87 is propelling particles away from it faster than 99% the speed of light.